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Development of a Krypton Fluoride Laser for Fusion Energy Research

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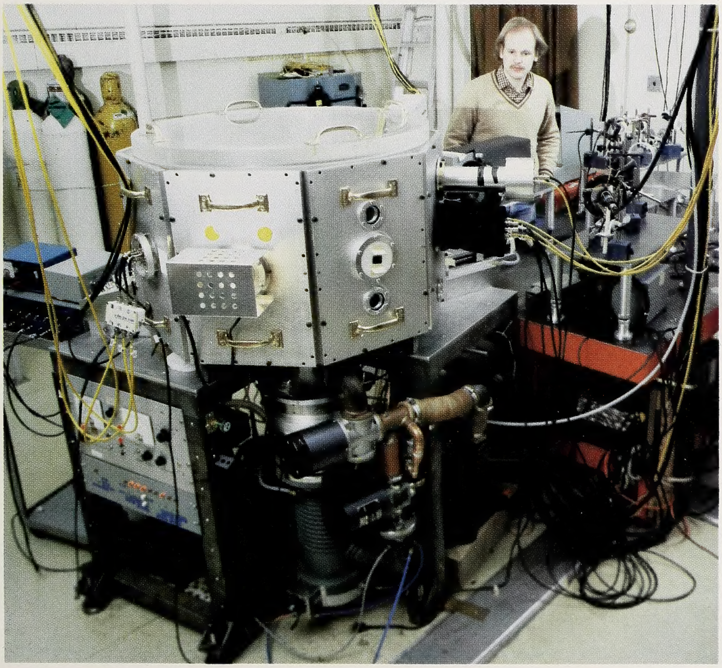
A project supported in part
by the Alberta/Canada
Energy Resources
Research Fund



Cover Photo: Target chamber used to study the effects of intense Krypton Fluoride (KrF) laser radiation on a variety of targets including plastic film, aluminium and gold.

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Foreword

Since 1976, numerous projects have been initiated in Alberta by industry and by academic research institutions which are aimed at better utilization of Alberta's energy resources.

These research, development and demonstration efforts were funded by the Alberta/Canada Energy Resources Research Fund (A/CERRF), which was established as a result of the 1974 agreement on oil prices between the federal government and the producing provinces.

Responsibility for applying and administering the fund rests with the A/CERRF Committee, made up of senior Alberta and federal government officials.

A/CERRF program priorities have focused on coal, energy conservation and renewable energy and conventional energy resources. Administration for the program is provided by staff within the Scientific and Engineering Services and Research Division of Alberta Energy.

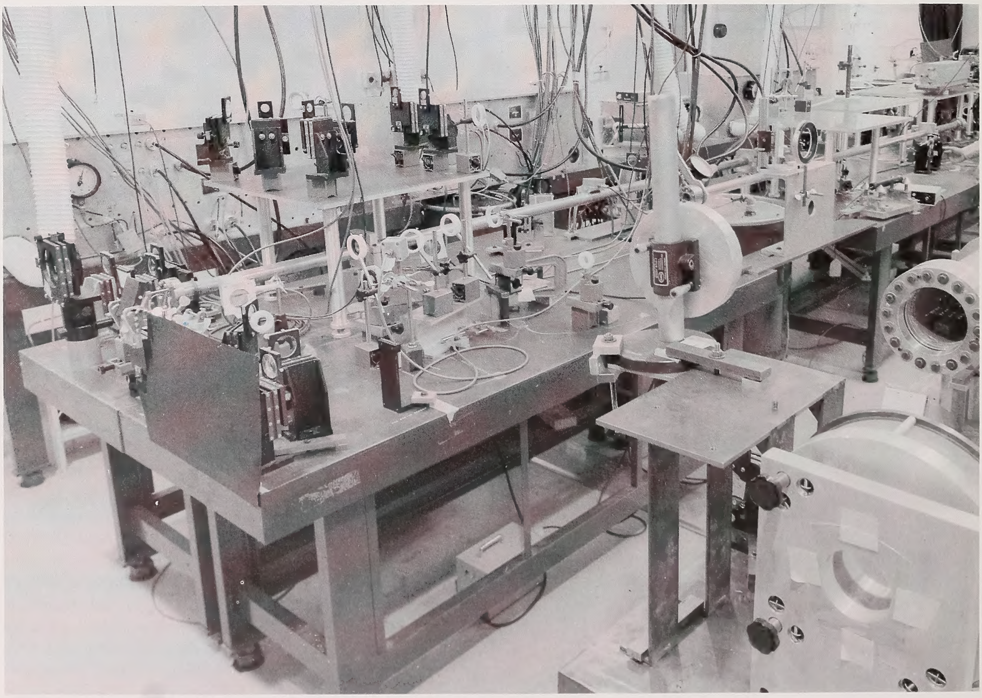
In order to make research results available to industry and others who can use the information, highlights of studies are reported in a series of technology transfer booklets. For more information about other publications in the series, please refer to page six.

Development of a Krypton Fluoride Laser for Fusion Energy Research

Nuclear fusion, the process that occurs in all stars and is the source of energy in the sun, is considered by many scientists to be the ultimate solution to the world's energy needs because it promises a virtually limitless supply of energy. Although the task of creating and controlling matter at the extreme temperature conditions found inside the sun represents one of the greatest technological challenges ever faced by mankind, the potential benefits are so great that major fusion research programs are underway throughout the world, notably in the United States, the Soviet Union, Japan and Europe. The fusion research effort in Canada is modest by comparison but has the potential to make significant contributions to what will be a long-term development of practical fusion systems.

There are two approaches to fusion research — Magnetic Confinement Fusion (MCF) and Inertial Confinement Fusion (ICF). In either approach, significant heating of the fuel is required in order to achieve the very high temperatures (100 million degrees Celsius) required to initiate and maintain fusion reactions. Lasers have the potential to provide the necessary energy to heat the fuel to ignition conditions in an ICF reactor. One laser that shows considerable promise is the krypton fluoride (KrF) excimer laser.

Because researchers in the Department of Electrical Engineering at the University of Alberta were keen to develop krypton fluoride laser technology and the A/CERRF Committee recognized the strategic importance of high power KrF laser technology for fusion and other applications, funds were provided by A/CERRF to develop an operational laser facility in Alberta.



Portion of KrF laser system showing (1) laser modules (left background), which generate and amplify long pulses and (2) auxiliary optics and high pressure gas pipes (right foreground), which convert long pulses into short pulses.

Background

Unlike fission reactions which involve the splitting of heavy nuclei (used in conventional nuclear power plants), fusion involves the joining together of two light nuclei. This process results in the release of energy in the form of particle energy and radiation.

In the process of heating the fuel to very high temperatures, a fourth state of matter, called plasma, is produced. In the plasma state, the particles become sufficiently energetic to overcome nuclear repulsion forces, thereby permitting fusion when particles collide. The energy released during fusion can result in a self-sustaining reaction.

In the Magnetic Confinement Fusion approach, a fusion reaction is initiated by applying an electrical discharge to a deuterium-tritium gas mixture to produce a hot plasma. Magnetic fields are used to confine the high temperature plasma. One class of magnetic confinement devices — called Tokamaks — is under development in several countries, including one in Canada at Varennes, Quebec.

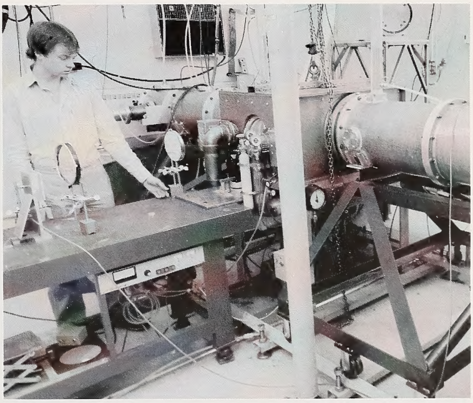
In the ICF approach, high power, short pulse lasers are used to compress and heat small pellets containing deuterium and tritium to fusion ignition conditions. In this case, magnetic fields are not required, potentially simplifying reactor construction and maintenance.

In the short twenty-five-year period since the invention of lasers, the science and technology of ultra-high power laser systems at different wavelengths has progressed markedly, motivated particularly by ICF research. As a consequence of using these lasers for fusion studies, it has been determined that short wavelength lasers (in the ultraviolet region of the spectrum) are likely to be the most suitable types to drive laser fusion reactions. One of the most promising is krypton fluoride (KrF) which lases when krypton and fluorine atoms are brought together in the presence of an electrical discharge. With the assistance of A/CERRF, a program to develop a KrF laser at the University of Alberta for fusion-related research was begun in 1980.

Results of A/CERRF-Supported Research

Prior to undertaking the KrF laser program, researchers at the University of Alberta, under the direction of Professor A.A. Offenberger, pursued for many years the development of high pulse power carbon dioxide (CO_2) lasers and their use for laser fusion research. Knowledge acquired from this research motivated the shift in emphasis from the long wavelength CO_2 laser to the short wavelength KrF laser.

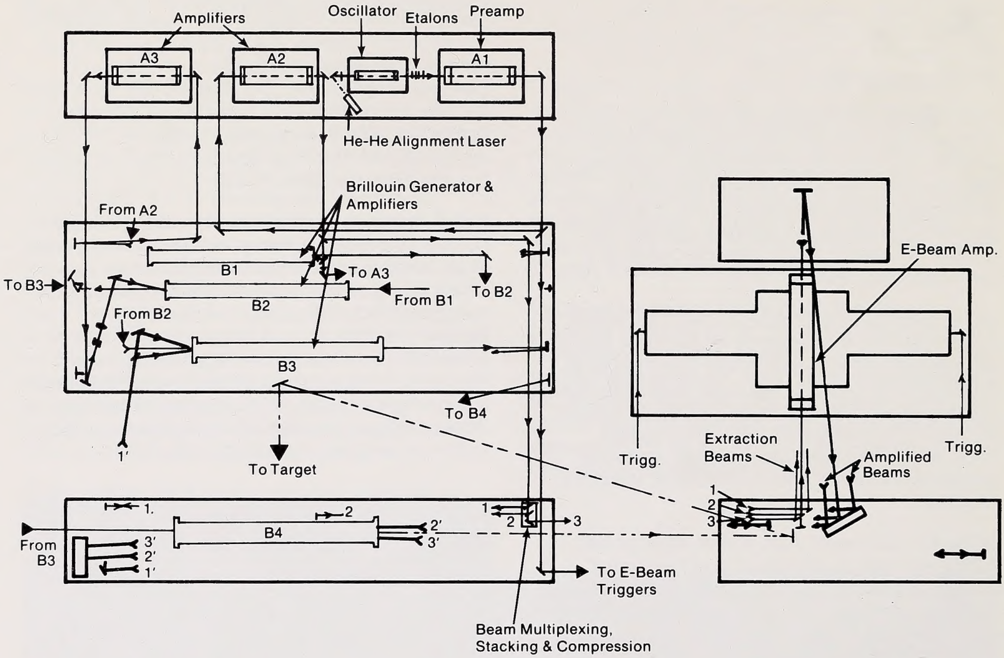
In the course of developing this laser system, a number of problems in key technology areas had to be addressed. Initially it was necessary to develop and characterize ultra-short pulse high voltage electrical discharge technology. A second problem arose due to the generation of unwanted by-products resulting from fluorine reactions in the laser discharge cavity. Therefore, it became necessary to incorporate newly developed gas processing capabilities into the system to remove unwanted products.



Electron-beam excited amplifier delivers high energy output pulses.

A third problem area arose because of the need for high precision, damage-resistant, ultraviolet materials and coatings. In many instances, as so often happens with emerging technologies, "off-the-shelf" components and instrumentation required to meet the special demands of frontier research are not available. This motivated the design and fabrication of many optical components and dielectric coatings both in-house and in co-operation with commercial suppliers.

Schematic diagram of KrF laser system showing Oscillator, Preamplifiers, Brillouin Cells and E-Beam Amplifier.



(Diagram: Courtesy of Dr. A.A. Offenberger, Dept. of Electrical Engineering, University of Alberta)

A fourth problem area involved the need for ultraviolet laser imaging and analysis. U of A researchers therefore developed electro-optical systems incorporating customized video cameras to monitor the laser beam and computers to store and analyze the video data.

A fifth — and perhaps the most important — problem involved the need to temporally compress the high energy laser pulses. Research on this topic has led to significant scientific advances in the laboratory at the University of Alberta. Although KrF lasers have the potential to be scaled to the very high energies required for fusion, efficient energy extraction requires long pulses. Consequently, in order to generate the high power short pulses required for fusion research, it is necessary to temporally compress the output of a KrF laser to a significant degree. The initial approach to pulse compression was to use a combination of optical beam multiplexing and a technique known as Stimulated Raman Scattering (SRS). During the course of these studies the researchers recognized that an alternative technique — Stimulated Brillouin Scattering (SBS) — could prove superior in terms of efficiency, compression ratio and in overcoming limitations imposed by the SRS process. Results of their SBS experiments have aroused worldwide interest in this new technique. Experience with both SRS and SBS has made the University of Alberta researchers among the most knowledgeable experts in the world in nonlinear pulse compression techniques.

During the four years of A/CERRF support, the researchers developed a unique prototype short pulse KrF laser system — the first of its type in the world — for laser fusion-related experiments. This was an important step in Alberta science and it has attracted many visiting scientists from around the world to learn more about the KrF laser system and to participate in the on-going research.

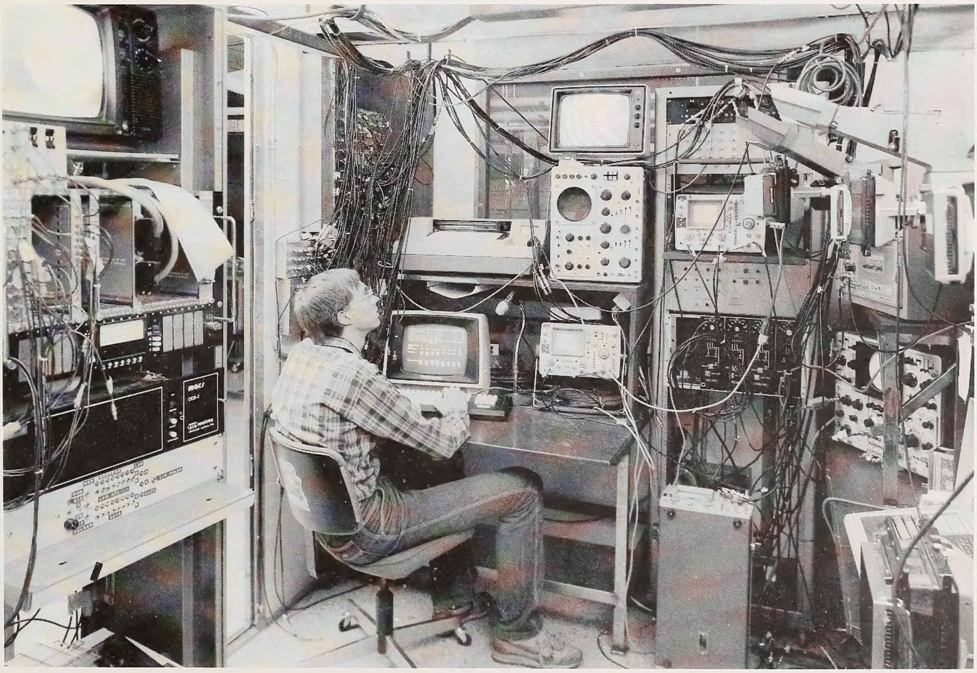
Benefits

The investment in people and facilities in the KrF laser laboratory at the University of Alberta has supported the research, education and training of many people including graduate and undergraduate students, postdoctoral fellows, visiting scientists and technicians who are using their knowledge of laser/plasma science and technology in government, industrial and academic laboratories throughout the world.

The technology developed at the University of Alberta has strategic importance not only for fusion, but also for near-term industrial applications, for example, in cutting and drilling ceramics, composite materials and highly reflecting metals such as copper and aluminum. Furthermore, KrF lasers have important characteristics, such as power, wavelength and focusing ability that are required for lithography (microcircuit fabrication), photochemistry and generation of X-rays for other applications in science, medicine and materials processing.

As a consequence of the successful research and development work supported by A/CERRF, the University of Alberta KrF laser laboratory has been able to secure continued funding from the Natural Sciences and Engineering Research Council (NSERC) to support on-going research programs. Thus, the A/CERRF-funded program achieved its objective — construction of an operational KrF laser facility — and served as a catalyst to establish the University of Alberta facility as one of the premier small-scale laser laboratories in the world.

The success of this program and the strategic importance of excimer lasers have led to a proposal by industry to establish a major national laser research centre in Edmonton founded on the KrF laser expertise of the University of Alberta researchers.



Control room of the KrF laser facility.

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